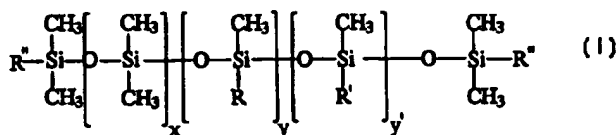




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(54) Title: DRY CLEANING SYSTEM USING DENSIFIED CARBON DIOXIDE AND A SURFACTANT ADJUNCT



## (57) Abstract

A system for dry cleaning soils from fabrics is described which contains densified carbon dioxide combined with a selected surfactant. The densified carbon dioxide is used in a temperature range of about -78.5 °C to about 100 °C and a pressure range of about 14.7 psi to about 10,000 psi. The surfactant is selected from one of two groups of compounds having formula (I) as described in the text or a second group of siloxane compounds having a formula [AB]<sub>y</sub> as described. A process for using the dry cleaning system is also described.

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**DRY CLEANING SYSTEM USING DENSIFIED CARBON DIOXIDE**  
**AND A SURFACTANT ADJUNCT**

**Field of the Invention**

- 5 This invention pertains to a dry cleaning system utilizing densified carbon dioxide and a particular surfactant adjunct.

**Background of the Invention**

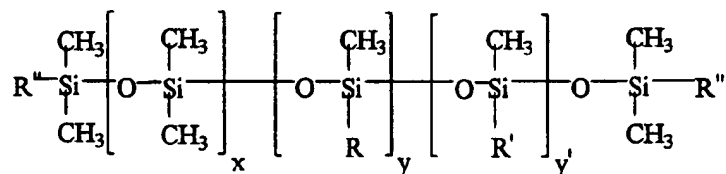
- 10 Densified carbon dioxide provides a nontoxic, inexpensive, recyclable and environmentally acceptable solvent to remove soils in the dry cleaning process. Effective dry cleaning systems using densified carbon dioxide in combination with selected surfactants are described in US-A-5,683,977, US-A-  
15 5,667,705 and US-A-5,683,473. Preferred surfactants described in these patents are combinations of densified carbon dioxide -philic and -phobic functional groups such as hydrocarbon/halocarbon and polymeric siloxane containing surfactants.
- 20 Applicants have further discovered additional selected surfactants which are both soluble in the densified solvent and effective for removing a variety of stains from a myriad of fabrics.

25 **Summary of the Invention**

- It is therefore an object of the present invention to provide additional selected surfactants which are combined with a nonpolar solvent, such as densified carbon dioxide, to provide a dry cleaning system which effectively removes  
30 a variety of soils on fabrics.

Another object of the invention is to provide a dry cleaning system of solvent, surfactant and optionally including a bleach or an enzyme for the total cleaning of fabrics using densified carbon dioxide that gives results equivalent to the cleaning demonstrated by conventional dry cleaning solvents.

In one aspect of the present invention, the dry cleaning systems used for cleaning a variety of soiled fabrics comprises densified carbon dioxide and about 0.001% to about 5% of a surfactant selected from one of two groups of compounds having the formula:



15

as described or  $[\text{AB}]_y$  as described.

The surfactant has a densified  $\text{CO}_2$ -philic functional moiety connected to a densified  $\text{CO}_2$ -phobic functional moiety.

Preferred  $\text{CO}_2$ -philic moieties of the surfactant include halocarbons such as fluorocarbons, chlorocarbons and mixed fluoro-chlorocarbons, polysiloxanes, and branched polyalkylene oxides. The  $\text{CO}_2$ -phobic groups for the surfactant contain preferably polyalkylene oxides, carboxylates,  $\text{C}_{1-30}$  alkylene sulfonates, carbohydrates, glycerates, phosphates, sulphates and  $\text{C}_{1-30}$  hydrocarbons.

The dry cleaning system may also be designed to include a modifier, such as water, or an organic solvent up to about

10% by volume, a bleaching agent such as a peracid, or an enzyme such as an amylase, protease, lipase or oxidase.

In a second aspect of the invention, a method for dry  
5 cleaning a variety of soiled fabrics is provided wherein a selected surfactant and optionally a modifier, bleaching agent, an enzyme or mixtures thereof are combined and the cloth is contacted with the mixture. Densified carbon dioxide is introduced into a cleaning vessel which is then  
10 pressurized from about 14.7 psi to about 10,000 psi and the temperature is adjusted to a range of about -78.5°C to about 100°C. Fresh densified carbon dioxide may be used to flush the cleaning vessel.

#### 15 Brief Description of the Drawing

Figure 1 is a diagrammatic flow chart of the densified carbon dioxide dry cleaning process according to the invention.

#### 20 Detailed Description of Preferred Embodiments

The invention provides a dry cleaning system which replaces conventional solvents with densified carbon dioxide in combination with selected cleaning surfactants.

Optionally, modifiers, bleaching agents, enzymes and  
25 mixtures thereof are combined with the solvent and surfactant to provide a total cleaning system.

For purposes of the invention, the following definitions are used:

30 "Densified carbon dioxide" means carbon dioxide that has a density (g/ml) greater than that of carbon dioxide gas at 1 atm and 20°C.

"Supercritical fluid carbon dioxide" means carbon dioxide which is at or above the critical temperature of 31°C and the critical pressure of 71 atmospheres and which cannot be  
5 condensed into a liquid phase despite the addition of further pressure.

The term "nonpolar stains" refers to those which are at least partially made by nonpolar organic compounds such as  
10 oily soils, sebum and the like.

The term "polar stains" is interchangeable with the term "hydrophilic stains" and refers to stains such as grape juice, coffee and tea.

15

The term "compound hydrophobic stains" refers to stains such as lipstick and red candle wax.

The term "particulate soils" means soils containing  
20 insoluble solid components such as silicates, carbon black, etc.

Densified carbon dioxide, preferably liquid or supercritical fluid carbon dioxide, is used in the  
25 inventive dry cleaning system. It is noted that other molecules having densified properties may also be employed alone or in mixture. These molecules include methane, ethane, propane, ammonia, butane, n-pentane, n-hexane, cyclohexane, n-heptane, ethylene, propylene, methanol,  
30 ethanol, isopropanol, benzene, toluene, p-xylene, sulfur dioxide, chlorotrifluoromethane, trichlorofluoromethane,

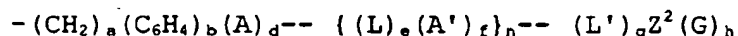
perfluoropropane, chlorodifluoromethane, sulfur hexafluoride and nitrous oxide.

During the dry cleaning process, the temperature range is between about -78.5°C and about 100°C, preferably about 5°C to about 60°C and most preferably about 5°C to about 25°C. The pressure during cleaning is about 14.7 psi to about 10,000 psi, preferably about 75.1 psi to about 7,000 psi and most preferably about 300 psi to about 6,000 psi.

10

A "substituted methylsiloxyl group" is a methylsiloxyl group substituted with a CO<sub>2</sub>-phobic group R<sup>2</sup> or R<sup>3</sup>. R<sup>2</sup> or R<sup>3</sup> are each represented in the following formula:

15



wherein a is 1-30, b is 0-1, C<sub>6</sub>H<sub>4</sub> is substituted or unsubstituted with a C<sub>1-10</sub> alkylene or alkenylene and A, d, L, e, A', F, n L', g, Z<sup>2</sup>, G and h are defined below.

20

A "substituted arylene" is an arylene substituted with a C<sub>1-30</sub> alkylene, alkenylene or hydroxyl, preferably a C<sub>1-20</sub> alkylene or alkenylene.

25 A "substituted carbohydrate" is a carbohydrate substituted with a C<sub>1-10</sub> alkylene or alkenylene, preferably a C<sub>1-5</sub> alkylene.

The terms "polyalkylene oxide", "alkylene" and "alkenylene" each contain a carbon chain which may be either straight or  
30 branched unless otherwise stated.

### Surfactant Adjuncts

A surfactant which is effective for use in a densified carbon dioxide dry cleaning system requires the combination of densified carbon dioxide-philic functional groups with  
5 densified carbon dioxide-phobic functional groups (see definitions above). The resulting compound may form reversed micelles with the CO<sub>2</sub>-philic functional groups extending into a continuous phase and the CO<sub>2</sub>-phobic functional groups directed toward the center of the  
10 micelle.

The surfactant is present in an amount of from 0.001 to 10 wt. %, preferably 0.01 to 5 wt.%.

The CO<sub>2</sub>-philic moieties of the surfactants are groups  
15 exhibiting low Hildebrand solubility parameters, as described in Grant, D.J. W. et al., "Solubility Behavior of Organic Compounds", Techniques of Chemistry Series, J. Wiley & Sons, N.Y. (1990) pp. 6-55 which describes the Hildebrand solubility equation, herein incorporated by  
20 reference. These CO<sub>2</sub>-philic moieties also exhibit low polarizability and some electron donating capability allowing them to be solubilized easily in densified fluid carbon dioxide.

25 As defined above, the CO<sub>2</sub>-philic functional groups are soluble in densified carbon dioxide to greater than 10 wt. %, preferably greater than 15 wt. %, at pressures of 500-10,000 psi and temperatures of 0°-100°C.

Preferred densified CO<sub>2</sub>-philic functional groups include  
30 halocarbons (such as fluoro-, chloro- and fluoro-chlorocarbons), polysiloxanes and branched polyalkylene oxides.



The CO<sub>2</sub>-phobic portion of the surfactant molecule is obtained either by a hydrophilic or a hydrophobic functional group which is less than 10 wt. % soluble in densified CO<sub>2</sub>, preferably less than 5 wt. %, at a pressure of about 14.7 to about 10,000 psi and temperatures about -78.5°C to about 100°C. Examples of moieties contained in the CO<sub>2</sub>-phobic groups include polyalkylene oxides, carboxylates, branched acrylate esters, C<sub>1-30</sub> hydrocarbons, aryls which are unsubstituted or substituted, sulfonates, glycerates,, phosphates, sulfates and carbohydrates. Especially preferred CO<sub>2</sub>-phobic groups include C<sub>2-20</sub> straight chain or branched alkyls, polyalkylene oxides, glycerates, carboxylates, phosphates, sulfates and carbohydrates.

15

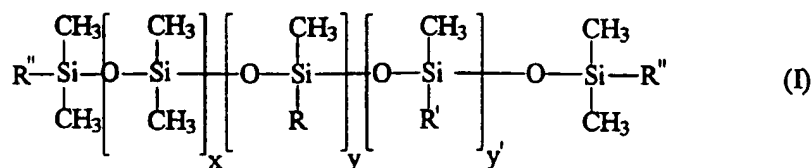
The CO<sub>2</sub>-philic and CO<sub>2</sub>-phobic groups may be directly connected or linked together via a linkage group. Such groups include ester, keto, ether, amide, amine, thio, alkyl, alkenylene, fluoroalkyl, fluoroalkenylene or fluoroalkenylene.

20

Surfactants which are useful in the invention may be selected from two groups of compounds.

#### 25 I. First Group

The first group of compounds has the following formula I:

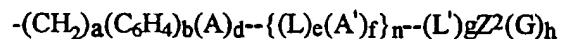


wherein the ratio of x:y and y' is greater than 0.5:1,  
preferably greater than 0.7:1 and most preferably greater  
than 1:1,

5

wherein, R, R', R'', and R''' are each independently CH<sub>3</sub>  
(with the proviso that they are not all CH<sub>3</sub>) or have the  
following formula:

10



wherein,

a is 1-30, preferably 1-25, most preferably 1-20.

b is 0 or 1,

15 C<sub>6</sub>H<sub>4</sub> is unsubstituted or substituted with a C<sub>1-10</sub> alkyl or  
alkenylene branched or straight chain, and

A and A' are each independently a linking moiety  
representing an ester, a keto, an ether, a thio, an amido,  
an amino, a C<sub>1-4</sub> fluoroalkylene, a C<sub>1-4</sub> fluoroalkenylene, a

20 branched or straight chain polyalkylene oxide, a phosphato,  
a sulfonyl, a sulfate, an ammonium, a lactam, and mixtures  
thereof;

d is 0 or 1;

L and L' are each independently a C<sub>1-30</sub> straight chain or

25 branched alkyl or alkenylene or an aryl which is  
unsubstituted or substituted and mixtures thereof;

e is 0-3;

f is 0 or 1;

n is 0-10, preferably 0-5, most preferably 0-3;

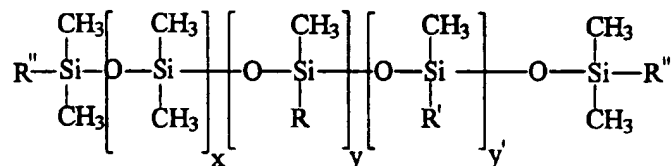
30 g is 0-3;

o is 0-5, preferably 0-3;

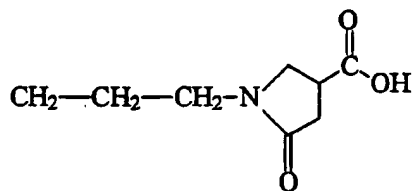
Z is a hydrogen, a carboxylic acid, a hydroxy, a phosphato, a phosphato ester, a sulfonyl, a sulfonate, a sulfate, a branched or straight-chained polyalkylene oxide, a nitryl, a glyceryl, an aryl unsubstituted or substituted with a C<sub>1-30</sub> alkylene or alkenylene, (preferably C<sub>1-25</sub> alkylene), a carbohydrate unsubstituted or substituted with a C<sub>1-10</sub> alkylene or alkenylene (preferably a C<sub>1-5</sub> alkylene) or an ammonium;

G is an anion or cation such as H<sup>+</sup>, Na<sup>+</sup>, Li<sup>+</sup>, K<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, Br<sup>-</sup>, I<sup>-</sup>, mesylate, or tosylate; and h is 0-3, preferably 0-2.

Non-limiting examples of this group of surfactants are:



x = 1-300, y = 1-100, y' = 1-100  
and R, R', R'', or R''' =



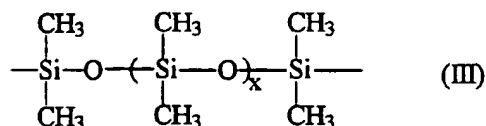
## 20 II. Second Group

The second group of compounds, for which Silsoft A-843 and Magnasoft SRS from Witco are commercially available examples, have the following structure II:



wherein,

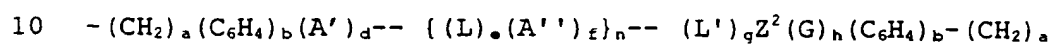
A is a repeating dimethyl siloxane unit:



5

x = 0-30,

B is a CO<sub>2</sub>-phobic group represented by R or R' where R or R' are independently represented by the formula:



wherein,

a is 1-30, preferably 1-25; most preferably 1-20,

b is 0 or 1,

15 C<sub>6</sub>H<sub>4</sub> is unsubstituted or substituted with a C<sub>1-10</sub> alkyl or alkenylene branched or straight, and

A' and A'' are each independently a linking moiety representing an ester, a keto, an ether, a thio, an amido, an amino, a C<sub>1-4</sub> fluoroalkyl, a C<sub>1-4</sub>

20 fluoroalkenylene, a branched or straight chain polyalkylene oxide, a phosphato, a sulfonyl, a sulfate, an ammonium, a lactam, and mixtures thereof;

d is 0 or 1;

L and L' are each independently a C<sub>1-30</sub> straight chained or branched alkyl or alkenylene or an aryl which is

25 unsubstituted or substituted and mixtures thereof;

e is 0-3;

f is 0 or 1;

n is 0-10, preferably 0-5, most preferably 0-3;

g is 0-3;

o is 0-5, preferably 0-3;

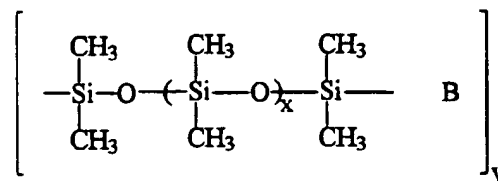
z is a hydrogen, a carboxylic acid, a hydroxy, a phosphato, a phosphato ester, a sulfonyl, a sulfonate, a sulfate, a branched or straight-chained polyalkylene oxide, a nitryl, a glyceryl, an aryl unsubstituted or substituted with a C<sub>1-30</sub> alkyl or alkenyl, (preferably C<sub>1-25</sub> alkyl), a carbohydrate unsubstituted or substituted with a C<sub>1-10</sub> alkyl or alkenylene (preferably a C<sub>1-5</sub> alkyl) or an ammonium;

G is an anion or cation such as H<sup>+</sup>, Na<sup>+</sup>, Li<sup>+</sup>, K<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, Ca<sup>+2</sup>, Mg<sup>+2</sup>, Cl<sup>-</sup>, Br<sup>-</sup>, I<sup>-</sup>, mesylate, or tosylate; and

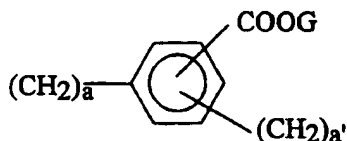
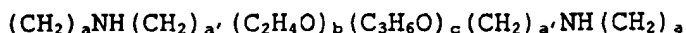
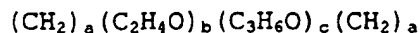
h is 0-3; preferably 0-2,

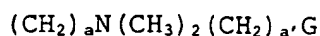
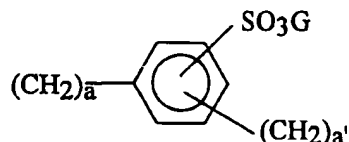
y is 2-100.

Nonlimiting examples of this [AB]<sub>y</sub> type surfactant are:



wherein y is 2-100, x is 0-30, and R and R' (i.e. B) =





5

$a = 1-30; a' = 1-30$

$b = 0-50; c = 0-50$

$G = H^+, Na^+, K^+, NH_4^+, Mg^{+2}, Ca^{+2}, Cl^-, Br^-, I^-,$  mesylate or tosylate.

10

Compounds of this type are prepared as described in US-A-4,150,048, incorporated herein by reference.

### 15 Modifiers

In a preferred embodiment, a modifier such as water, or a useful organic solvent may be added to the cleaning drum in a small volume. Water is specifically added into the drum. Water absorbed onto the fabrics to be drycleaned or present in residual amounts in the surfactant compound from the process of preparing the compounds is not calculated when determining the amount of the modifier which should be added. Preferred amounts of modifier should be 0.1% to about 10% by volume, more preferably 0.1% to about 5% by volume, most preferably 0.1% to about 3%. Preferred solvents include water, acetone, glycols, acetonitrile,  $C_{1-10}$  alcohols and  $C_{5-15}$  hydrocarbons. Especially preferred solvents include water, ethanol, methanol and hexane.

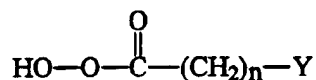
Peracid Precursors

Organic peracids which are stable in storage and which solubilize in densified carbon dioxide are effective at bleaching stains in the dry cleaning system. The selected organic peracid should be soluble in carbon dioxide to greater than 0.001 wt. % at pressures of about 500 to about 10,000 psi and temperatures of about 0°C to about 100°C. The peracid compound should be present in an amount of about 0.01% to about 5%, preferably 0.1% to about 3%.

10

The organic peroxyacids usable in the present invention can contain either one or two peroxy groups and can be either aliphatic or aromatic. When the organic peroxy acid is aliphatic, the unsubstituted acid has the general formula:

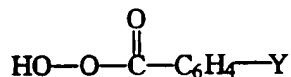
15



where Y can be, for example, H, CH<sub>3</sub>, CH<sub>2</sub>Cl, COOH, or COOH; and n is an integer from 1 to 20.

20

When the organic peroxy acid is aromatic, the unsubstituted acid has the general formula:



25

wherein Y is hydrogen, alkylene, alkylenehalogen, halogen, or COOH or COOH.

Typical monoperoxyacids useful herein include alkylene peroxyacids and arylene peroxyacids such as:

- (i) peroxybenzoic acid and ring-substituted peroxybenzoic acid, e.g. peroxy-*m*-naphthoic acid;
- (ii) aliphatic, substituted aliphatic and arylenealkylene monoperoxy acids, e.g. peroxy lauric acid, peroxy stearic acid, and *N,N*-phthaloylaminoperoxy caproic acid (PAP); and
- (iii) amidoperoxy acids, e.g. monononylamide of either peroxy succinic acid (NAPSA) or of peroxy adipic acid (NAPAA).

Typical diperoxy acids useful herein include alkylene  
10 diperoxy acids and arylenediperoxy acids, such as:

- (iv) 1,12-diperoxy dodecanedioic acid;
- (v) 1,9-diperoxy azelaic acid;
- (vi) diperoxy brassylic acid; diperoxy sebacic acid and diperoxy isophthalic acid;
- 15 (vii) 2-decyldiperoxy butane-1,4-dioic acid;
- (viii) 4,4'-sulfonylbis peroxy benzoic acid; and
- (ix) *N,N'*-terephthaloyl-di(6-aminoperoxy caproic acid) (TPCAP).

20 Particularly preferred peroxy acids include PAP, TPCAP, haloperbenzoic acid and peracetic acid.

### Enzymes

Enzymes may additionally be added to the dry cleaning  
25 system of the invention to improve stain removal. Such enzymes include proteases (e.g., Alcalase®, Savinase® and Esperase® from Novo Industries A/S; amylases (e.g., Termamyl® and Duramyl® bleach resistant amylases from Novo Industries A/S); lipases (e.g., Lipolase® from Novo  
30 Industries A/S); and oxidases. The enzyme should be added to the cleaning drum in an amount from 0.001% to 10%, preferably 0.01% to 5%. The type of soil dictates the



choice of enzyme used in the system. The enzymes should be delivered in a conventional manner, such as by preparing an enzyme solution, typically of 1% by volume (i.e., 3 mls enzyme in buffered water or solvent).

5

#### Dry Cleaning Process

A process of dry cleaning using densified carbon dioxide as the cleaning fluid is schematically represented in Figure 1. A cleaning vessel 5, preferably a rotatable drum, receives soiled fabrics as well as the selected surfactant, and any modifier, peracid and mixtures thereof. The cleaning vessel may also be referred to as an autoclave, particularly as described in the examples below.

15 Densified carbon dioxide is introduced into the cleaning vessel from a storage vessel 1. Since much of the CO<sub>2</sub> cleaning fluid is recycled within the system, any losses during the dry cleaning process are made up through a CO<sub>2</sub> supply vessel 2. The CO<sub>2</sub> fluid is pumped into the cleaning vessel by a pump 3 at pressures ranging between about 14.7 and about 10,000 psi, preferably about 300 to about 7000 psi, most preferably about 800 psi to about 6000 psi. The CO<sub>2</sub> fluid is maintained at temperatures of about -78.5°C to about 100°C, preferably about 50°C to about 60°C, most preferably about 5°C to about 60°C by a heat exchanger 4, or by pumping a cooling solution through an internal condenser.

As an example of the operation of the system, the densified CO<sub>2</sub> is transferred from the supply vessel 2 to the cleaning vessel 5 through line 7 for a dry cleaning cycle of between about 15 to about 30 minutes. Before or during the

cleaning cycle, surfactants, modifiers, enzymes, peracid and mixtures thereof as discussed above are introduced into the cleaning vessel, preferably through a line and pump system connected to the cleaning vessel.

5

At the end of the dry cleaning cycle, dirty CO<sub>2</sub>, soil and spent cleaning agents are transferred through an expansion valve 6, a heat exchanger 8 by way of a line 9 into a flash drum 10. In the flash drum, pressures are reduced to  
10 between about 260 and about 1,000 psi and to a temperature of about 23°C to about 60°C. Gaseous CO<sub>2</sub> is separated from the soil and spent agents and transferred via line 11 through a filter 12 and condenser 13 to be recycled back to the supply vessel 2. Any pressure losses are recovered by  
15 using pump 16. The spent agents and residue CO<sub>2</sub> are transferred via line 14 to an atmospheric tank 15, where the remaining CO<sub>2</sub> is vented to the atmosphere.

Other processes known in the art may be used in the claimed  
20 dry cleaning system such as those described in US-A-5,267,455 and JP 08052297, herein incorporated by reference.

The following examples will more fully illustrate the  
25 embodiments of the invention. All parts, percentages and proportions referred to herein and in appended claims are by weight unless otherwise indicated. The definitions and examples are intended to illustrate and not limit the scope of the invention.

30

Example 1

The hydrophilic stain, grape juice, was dry cleaned using liquid carbon dioxide, a polydimethylsiloxane surfactant, water as a modifier and mixtures thereof according to the invention.

Two inch by three inch polyester cloths were cut and soaked in concentrated grape juice which was diluted 1:4 with water. The cloths were then removed and dried overnight on plastic sheets. The stained fabrics were then placed in a 300 ml autoclave having a gas compressor and an extraction system as shown in Figure 1. The stained cloth was hung from the bottom of the autoclave's overhead stirrer using a copper wire to promote good agitation during washing and extraction. After placing the cloth in the autoclave and sealing it, liquid CO<sub>2</sub> at a tank pressure of 850 psi was allowed into the system and was cooled to reach a temperature of about 11°C at which point the liquid CO<sub>2</sub> was at a pressure of about 800 psi. The stirrer was then turned on for 15 minutes to mimic a wash cycle. At the completion of the wash cycle, 20 cubic feet of fresh CO<sub>2</sub> were passed through the system to mimic a rinse cycle. The pressure of the autoclave was then released to atmospheric pressure and the cleaned cloths were removed from the autoclave. To measure the extent of cleaning, spectrophotometric readings were taken using a Hunter Ultrascan XE<sup>7</sup> spectrophotometer. The R scale, which measures darkness from black to white, was used to determine stain removal. Cleaning results were reported as the percent stain removal according to the following calculation:

$$\% \text{ stain removal} = \frac{\text{stain removed}}{\text{stain applied}} = \frac{\text{cleaned cloth reading} - \text{stained cloth reading}}{\text{unstained cloth reading} - \text{stained cloth reading}} \times 100\%$$

Two different polydimethylsiloxane surfactants were used alone or in combination with 0.5 ml of water and liquid carbon dioxide. The control was liquid carbon dioxide alone.

The water was added directly to the bottom of the autoclave and not on the stain itself and the surfactant was applied directly to the stain on the cloth. After the wash and 10 rinse cycles, cleaning results were evaluated and the results are reported in Table 1 below.

15

Table 1

**Dry Cleaning Results on Grape Juice Stains Using Supercritical Carbon Dioxide and Polydimethylsiloxane Surfactant**

Stain	Substrate	Surfactant	Modifier	Removal %
grape juice	Polyester	None	None	2.5
grape juice	Polyester	None	0.5 ml water	0.3
grape juice	Polyester	0.67 g Silsoft A-843 <sup>1</sup>	0.5 ml water	13.6
grape juice	Polyester	0.2 g Monasil PCA <sup>2</sup>	0.5 ml water	19.0

20

<sup>1</sup> Supplied by Witco; [AB]<sub>y</sub> silicone copolymer.

<sup>2</sup> Supplied by Mona Industries; lactam modified silicone copolymer.

25 It was observed that the combination of water as a modifier with the selected silicone surfactants improved dry cleaning

results in liquid carbon dioxide. Liquid carbon dioxide alone or with water added did not appreciably clean the stain.

5 Example 2

The hydrophilic stain, grape juice, was dry cleaned using liquid carbon dioxide, and mixtures of liquid carbon dioxide, polydimethylsiloxane surfactant, and water according to the invention.

10

8.75" X 4.75" cloths had a 2" diameter circle inscribed in pencil in the middle and concentrated grape juice which was diluted 1:4 with water was applied using a micropipet to the inside of the circles and spread to the edges of the  
15 circle. The following amounts were used: on polyester and wool, 475 microliters; on cotton 350 microliters; and on silk, 2 applications of 200 microliters with 15 minutes in between applications. The cloths were then dried overnight. Four replicates of each cloth type (for a total of 12

20 cloths) were placed in the cleaning chamber of a CO<sub>2</sub> dry cleaning unit constructed as taught in US patent 5,467,492 and employing hydrodynamic agitation of garments by use of appropriately angled nozzles. To simulate a full load of clothes, 1.5 pounds of cotton ballast sheets (11" X 11")  
25 were also placed in the cleaning chamber. The dry cleaning unit employed had a cleaning chamber which holds about 76 liters of liquid CO<sub>2</sub>. The piping in the cleaning loop held an additional 37 liters for a total volume in the cleaning loop of 113 liters. There was also a storage tank on the  
30 unit from which the fresh liquid CO<sub>2</sub> was added once the chamber door was closed and sealed. The cleaning cycle lasted for 15 minutes at about 850 psi and 11 degrees Celsius. After the cleaning cycle, the liquid CO<sub>2</sub> in the

cleaning loop was pumped back into the storage tank, and the chamber door opened. To measure the extent of cleaning, spectrophotometric readings were taken on the washed grape juice cloths using a Hunter Ultrascan XE<sup>7</sup> spectrophotometer.

- 5 The L,a,b scale was used to measure cleaning. Cleaning results were reported as stain removal index values (SRI's) using the following calculation:

10 
$$SRI = 100 - \sqrt{(L_{washed} - L_{clean})^2 + (a_{washed} - a_{clean})^2 + (b_{washed} - b_{clean})^2}$$

where,

L measures black to white differences,

a measures green to red differences

- 15 and, b measures blue to yellow differences.

Two experiments were run - concentrations are in weight/volume of CO<sub>2</sub>:

- 20 1. no additive (liquid CO<sub>2</sub> alone)  
2. 0.05% Monasil PCA + 0.075% water

Surfactant and water were premixed and added directly to  
25 the bottom of the cleaning chamber below the ballast and not on the stains themselves. After the wash cycle removal of CO<sub>2</sub> from the cleaning chamber, cleaning results were evaluated, and are reported in Table 2 below.

Table 2

Stain	Fabric	Experiment Number	Stain Removal Index
grape juice	wool (LSD* = 4.90)	2	72.90
		1	65.06
	polyester (LSD = 3.51)	2	71.63
		1	61.41
	cotton (LSD = 1.03)	2	63.45
		1	61.35

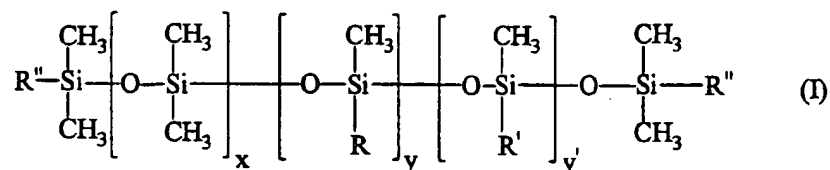
\*LSD stands for the "least significant difference" and the 5 numbers shown are at the 95% confidence level.

It was observed that for all three cloth types studied, addition of Monasil PCA plus water improved the dry cleaning results in liquid carbon dioxide.

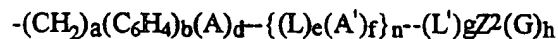
# Claims

1. A dry cleaning system for removing stains from fabrics comprising:

- (a) an effective amount of densified carbon dioxide;
- (b) 0.001% to 10% by weight of a surfactant compound selected from the group consisting of
  - i) compounds of formula I



wherein the ratio of x:y and y' is greater than 0.5:1, R, R', R'' are each independently CH<sub>3</sub>, with the proviso that they are not all CH<sub>3</sub>, or have the following formula:



a is 1-30,

b is 0 or 1,

C<sub>6</sub>H<sub>4</sub> is unsubstituted or substituted with a C<sub>1-10</sub> alkyl or alkenylene which is a branched or straight chain,

A and A' are each independently a linking moiety representing an ester, a keto, an ether, a thio, an amido, an amino, a C<sub>1-4</sub> fluoroalkylene, a C<sub>1-4</sub> fluoroalkenylene, a branched or straight chain polyalkylene oxide, a phosphato, a sulfonyl, a sulfate, an ammonium, a lactam, and mixtures thereof,

d is 0 or 1;



L and L' are each independently a C<sub>1-30</sub> straight chained or branched alkylene or alkenylene or an aryl which is unsubstituted or substituted and mixtures thereof;

e is 0-3;

f is 0 or 1;

n is 0-10;

g is 0-3;

o is 0-5;

Z is a hydrogen, a carboxylic acid, a hydroxy, a phosphato, a phosphato ester, a sulfonyl, a sulfonate, a sulfate, a branched or straight-chained polyalkylene oxide, a nitryl, a glyceryl, an aryl unsubstituted or substituted with a C<sub>1-30</sub> alkylene or alkenylene, (preferably C<sub>1-25</sub> alkyl), a carbohydrate unsubstituted or substituted with a C<sub>1-10</sub> alkylene or alkenylene (preferably a C<sub>1-5</sub> alkyl) or an ammonium;

G is an anion or cation such as H<sup>+</sup>, Na<sup>+</sup>, Li<sup>+</sup>, K<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, Ca<sup>+2</sup>, g<sup>+2</sup>, Cl<sup>-</sup>, Br<sup>-</sup>, I<sup>-</sup>, mesylate, or tosylate,

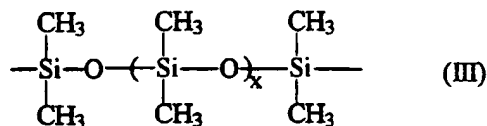
h is 0-3,

or

ii) compounds of formula II

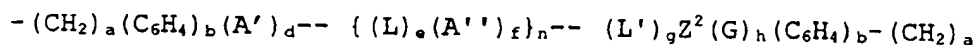


wherein A is a repeating dimethyl siloxane unit:



x = 0-30,

B is a CO<sub>2</sub>-phobic group represented by R or R' where R or R' are independently represented by the formula:



wherein,

a is 1-30,

b is 0 or 1,

C<sub>6</sub>H<sub>4</sub> is unsubstituted or substituted with a C<sub>1-10</sub> alkylene or alkenylene branched or straight, and

A' and A'' are each independently a linking moiety representing an ester, a keto, an ether, a thio, an amido, an amino, a C<sub>1-4</sub> fluoroalkylene, a C<sub>1-4</sub> fluoroalkenylene, a branched or straight chain polyalkylene oxide, a phosphato, a sulfonyl, a sulfate, an ammonium, a lactam, and mixtures thereof,

d is 0 or 1,

L and L' are each independently a C<sub>1-30</sub> straight chained or branched alkylene or alkenylene or an aryl which is unsubstituted or substituted and mixtures thereof,

e is 0-3,

f is 0 or 1,

n is 0-10,

g is 0-3,

o is 0-5,

Z is a hydrogen, a carboxylic acid, a hydroxy, a phosphato, a phosphato ester, a sulfonyl, a sulfonate, a sulfate, a branched or straight-chained polyalkylene oxide, a nitryl, a glyceryl, an aryl unsubstituted or substituted with a C<sub>1-30</sub> alkylene or alkenylene, (preferably C<sub>1-25</sub> alkylene), a carbohydrate unsubstituted or substituted with a C<sub>1-10</sub> alkylene or alkenylene (preferably a C<sub>1-5</sub> alkylene) or an

ammonium;

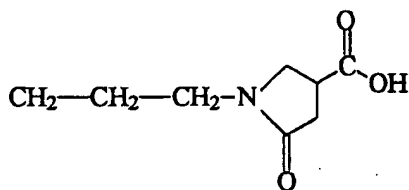
G is an anion or cation such as  $H^+$ ,  $Na^+$ ,  $Li^+$ ,  $K^+$ ,  $NH_4^+$ ,  $Ca^{+2}$ ,  $Mg^{+2}$ ,  $Cl^-$ ,  $Br^-$ ,  $I^-$ , mesylate, or tosylate,

h is 0-3,

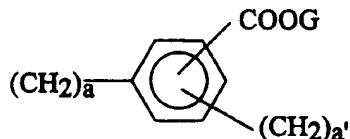
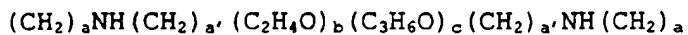
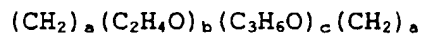
y is 2-100, and

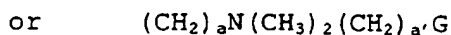
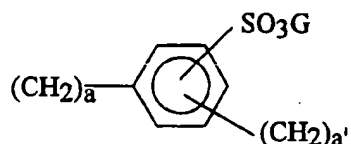
mixtures of compounds I and II.

2. The system according to claim 1 wherein the compounds of formula I are those wherein x is 1-300, y is 1 to 100, y is 1 to 100 and R, R', R'' or R'''' are each independently selected from the group consisting of:



3. The system according to claim 1 wherein the compounds of formula II are those wherein y is 2 to 100, x is 0 to 30 and R and R' are each independently selected from the group consisting of:





$a = 1-30; a' = 1-30$

$b = 0-50; c = 0-50$

$\text{G} = \text{H}^+, \text{Na}^+, \text{K}^+, \text{NH}_4^+, \text{Mg}^{+2}, \text{Ca}^{+2}, \text{Cl}^-, \text{Br}^-, \text{I}^-, \text{mesylate or tosylate}.$

4. The system according to claim 1 further comprising 0.1% to about 10% by volume of a modifier selected from the group consisting of water, acetone, a glycol, acetonitrile, C<sub>1-10</sub> alcohol and C<sub>5-15</sub> hydrocarbon.

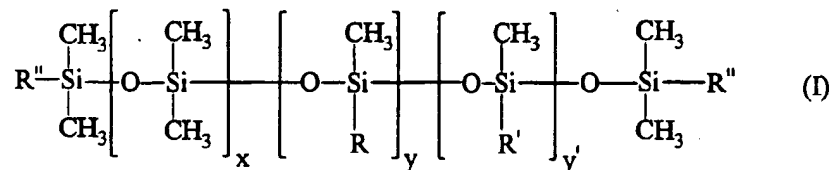
5. The system according to claim 1 wherein the densified carbon dioxide is in a liquid phase having a pressure of about 14.7 psi to about 10,000 psi and a temperature of about -78.5°C to about 100°C.

6. The system according to claim 1 wherein the system further comprises an organic peracid selected from the group consisting of N,N-phthaloylaminoperoxycaproic acid (PAP) and N,N'-terephthaloyl-di(6-aminoperoxycaproic acid (TPCAP), a haloperbenzoic acid and peracetic acid.

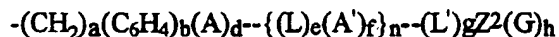
7. A method of drycleaning fabrics comprising:

1) selecting a drycleaning system comprising

- (a) an effective amount of densified carbon dioxide;  
 (b) 0.001% to 10% by weight of a surfactant compound selected from the group consisting of  
 i) compounds of formula I



wherein the ratio of  $x:y$  and  $y'$  is greater than 0.5:1,  $\text{R}$ ,  $\text{R}'$ ,  $\text{R}''$  are each independently  $\text{CH}_3$ , with the proviso that they are not all  $\text{CH}_3$ , or have the following formula:



$a$  is 1-30,

$b$  is 0 or 1,

$\text{C}_6\text{H}_4$  is an unsubstituted or substituted with a  $\text{C}_{1-10}$  alkyl or alkenylene which is a branched or straight chain,

$\text{A}$  and  $\text{A}'$  are each independently a linking moiety representing an ester, a keto, an ether, a thio, an amido, an amino, a  $\text{C}_{1-4}$  fluoroalkylene, a  $\text{C}_{1-4}$  fluoroalkenylene, a branched or straight chain polyalkylene oxide, a phosphato, a sulfonyl, a sulfate, an ammonium, a lactam, and mixtures thereof,

$d$  is 0 or 1;

$\text{L}$  and  $\text{L}'$  are each independently a  $\text{C}_{1-30}$  straight chained or branched alkylene or alkenylene or an aryl which is unsubstituted or substituted and mixtures thereof;

$e$  is 0-3;

f is 0 or 1;

n is 0-10;

g is 0-3;

o is 0-5;

Z is a hydrogen, a carboxylic acid, a hydroxy, a phosphato, a phosphato ester, a sulfonyl, a sulfonate, a sulfate, a branched or straight-chained polyalkylene oxide, a nitril, a glyceryl, an aryl unsubstituted or substituted with a C<sub>1-30</sub> alkylene or alkenylene, (preferably C<sub>1-25</sub> alkyl), a carbohydrate unsubstituted or substituted with a C<sub>1-10</sub> alkylene or alkenylene (preferably a C<sub>1-5</sub> alkyl) or an ammonium;

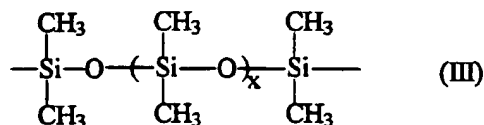
G is an anion or cation such as H<sup>+</sup>, Na<sup>+</sup>, Li<sup>+</sup>, K<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, Ca<sup>+2</sup>, Mg<sup>+2</sup>, Cl<sup>-</sup>, Br<sup>-</sup>, I<sup>-</sup>, mesylate, or tosylate,

h is 0-3, or

ii) compounds of formula II

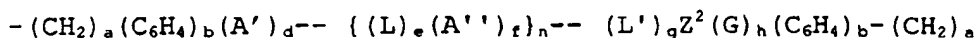


wherein A is a repeating dimethyl siloxane unit:



x = 0-30,

B is a CO<sub>2</sub>-phobic group represented by R or R' where R or R' are independently represented by the formula:



wherein,

a is 1-30,

b is 0 or 1,

$\text{C}_6\text{H}_4$  is unsubstituted or substituted with a  $\text{C}_{1-10}$  alkylene or alkenylene branched or straight, and

$\text{A}'$  and  $\text{A}''$  are each independently a linking moiety representing an ester, a keto, an ether, a thio, an amido, an amino, a  $\text{C}_{1-4}$  fluoroalkylene, a  $\text{C}_{1-4}$  fluoroalkenylene, a branched or straight chain polyalkylene oxide, a phosphato, a sulfonyl, a sulfate, an ammonium, a lactam, and mixtures thereof,

d is 0 or 1,

L and L' are each independently a  $\text{C}_{1-30}$  straight chained or branched alkylene or alkenylene or an aryl which is unsubstituted or substituted and mixtures thereof,

e is 0-3,

f is 0 or 1,

n is 0-10,

g is 0-3,

o is 0-5,

Z is a hydrogen, a carboxylic acid, a hydroxy, a phosphato, a phosphato ester, a sulfonyl, a sulfonate, a sulfate, a branched or straight-chained polyalkylene oxide, a nitril, a glyceryl, an aryl unsubstituted or substituted with a  $\text{C}_{1-30}$  alkylene or alkenylene, (preferably  $\text{C}_{1-25}$  alkylene), a carbohydrate unsubstituted or substituted with a  $\text{C}_{1-10}$  alkylene or alkenylene (preferably a  $\text{C}_{1-5}$  alkylene) or an ammonium;

G is an anion or cation such as  $\text{H}^+$ ,  $\text{Na}^+$ ,  $\text{Li}^+$ ,  $\text{K}^+$ ,  $\text{NH}_4^+$ ,  $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ ,  $\text{Cl}^-$ ,  $\text{Br}^-$ ,  $\text{I}^-$ , mesylate, or tosylate,

h is 0-3,  
y is 2-100, and  
mixtures of compounds I and II; and

2) cleaning soils from fabrics in a drycleaning cycle.

8. The method according to claim 7 wherein the densified carbon dioxide of the system is introduced into a cleaning vessel at a pressure having from between about 14.7 to about 10,000 psi.

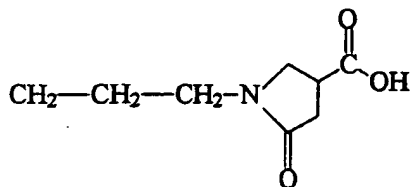
9. The method according to claim 8 wherein the densified carbon dioxide is maintained at a temperature of about -78.5°C to about 100°C during the cleaning step (2).

10. The method according to claim 7 wherein a modifier is further introduced during the cleaning step (2) in an amount of 0.1% to 10% by volume.

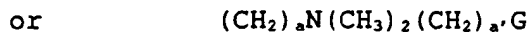
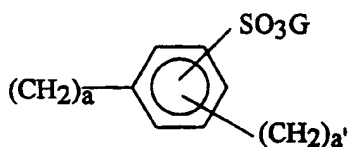
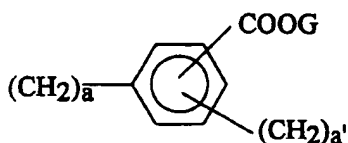
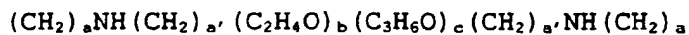
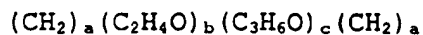
11. The method according to claim 10 wherein the modifier is selected from the group consisting of water, acetone, a glycol, acetonitrile, C<sub>1</sub>-C<sub>10</sub> alcohol and C<sub>5</sub>-C<sub>15</sub> hydrocarbon.

12. The method according to claim 7 wherein the compounds of formula I are those wherein x is 1-300, y is 1 to 100, y is 1 to 100 and R, R', R'' or R'''' are each independently selected from the group consisting of:





13. The method according to claim 7 wherein the compounds of formula II are those wherein  $y$  is 2 to 100,  $x$  is 0 to 30 and  $R$  and  $R'$  are each independently selected from the group consisting of:



$a = 1-30$ ;  $a' = 1-30$

$b = 0-50$ ;  $c = 0-50$

$G = \text{H}^+, \text{Na}^+, \text{K}^+, \text{NH}_4^+, \text{Mg}^{+2}, \text{Ca}^{+2}, \text{Cl}^-, \text{Br}^-, \text{I}^-, \text{mesylate}$  or tosylate.

14. The method according to claim 7 wherein the system further comprises an organic peracid selected from the group consisting of N,N-phthaloylaminoperoxyacaproic acid (PAP) and N,N'-terephthaloyl-di(6-aminoperoxyacaproic acid (TPCAP), a haloperbenzoic acid and peracetic acid.

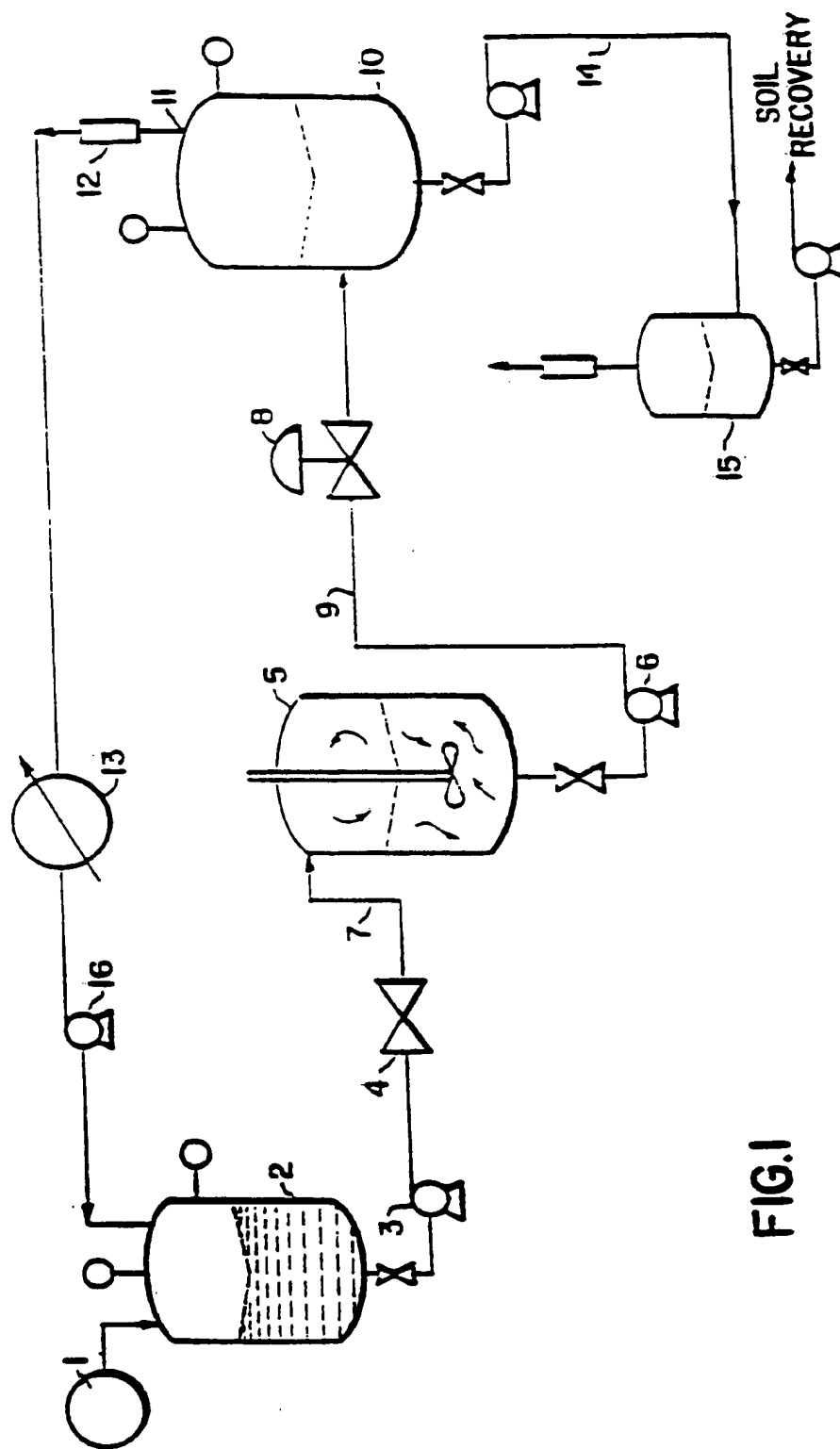


FIG. 1

## INTERNATIONAL SEARCH REPORT

Int'l Application No

PCT/EP 99/02770

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 D06L1/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 D06L C11D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 27704 A (UNILEVER ) 12 September 1996 (1996-09-12) cited in the application page 29, line 14 - page 35, line 35 page 36, line 35 - page 37, line 30; claims 1,5-7,9 & US 5 683 977 A ---	1,4-11, 14
P,X	WO 99 10587 A (MICELL TECHNOLOGIES ) 4 March 1999 (1999-03-04) page 2, line 21 - line 22 page 4, line 14 - page 5, line 29 page 6, line 21 - line 24; claims 1,7 ---	1,4,5,7, 8,10,11
A	WO 97 16264 A (UNIV NORTH CAROLINA ) 9 May 1997 (1997-05-09) claims 1-17; example 25 ---	1,4,7, 10,11
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☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

## \* Special categories of cited documents:

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"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"A" document member of the same patent family

Date of the actual completion of the international search

5 August 1999

Date of mailing of the international search report

19/08/1999

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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/EP 99/02770

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